

PATENT APPLICATION BASED ON:

Docket No:

83,025

Inventors:

Jiebo Luo
Qing Yu

Attorney:

Thomas H. Close

DIGITAL IMAGE MULTITONING METHOD

Commissioner for Patents
Attn: Box Patent Application
Washington, DC 20231

Express Mail Label No: *EL 656969361LLS*

Date: *June 29, 2001*

09696798-062901

DIGITAL IMAGE MULTITONING METHOD

FIELD OF THE INVENTION

The present invention relates generally to a method and system for
5 forming multi-level halftone images from an input digital image, which minimize
the perceived noise level in the multitone image.

BACKGROUND OF THE INVENTION

For the purpose of printing images from a graphical display, such
10 as the display screen of a computer, many such displays are typically only capable
of printing binary images. In other words, at each position of the image there are
only two possible output states, colorant or no colorant. For example, a
traditional graphic arts printing press will either disperse ink or withhold ink at
each location of the image. For monochrome imaging systems, this means that an
15 image can only be made up of pixels that are either black or white. To create the
illusion of continuous tone images, methods referred to in the art as "halftoning
techniques" have been developed. With these techniques, the appearance of
intermediate gray levels is created by taking advantage of the fact that the human
eye acts as a low-pass filter and will average the intensity over a small local area
20 of the image. It is, therefore, possible to locally vary the ratio between the white
area and the black area to form varying levels of gray.

Although, historically, halftone dot patterns were created optically
for images made on printing presses, presently the majority of halftone images are
created on a computer using one of many presently known and utilized digital
25 halftoning algorithms. Two widely used halftoning algorithms for digital printers,
such as laser writers, are generally referred to in the art as periodic dither and
error diffusion.

Although halftoning techniques were originally developed for
binary output devices, recent developments have made them available for multi-
30 level output devices or, in other words, devices that produce a variety of different

colorant levels. (For example see: R. S. Gentile, E. Walowit and J. P. Allebach, "Quantization and multilevel halftoning of color images for near original image quality," J. Opt. Soc. Am. A 7, 1019-1026 (1990)). There are several motivations in the art for performing multi-level halftoning. First, some output devices may only be capable of producing a limited set of output colors. For such displays, noticeable artifacts, such as contouring, will result if simple quantization methods are used to produce the image. Contouring is the visible transitions between adjacent output levels that typically result when many input levels are mapped to a single output level.

Multi-level halftoning methods eliminate contouring artifacts by preserving the original average color level in a local image region. In some cases, the number of output colors of the display device is large enough so that contouring does not occur and, as a result, multi-level halftoning is generally not necessary. Even in such a case, there may be advantages to using multi-level halftoning techniques. For example, it may be possible to reduce the amount of RAM required in a printer or the disk-space required for an image file by reducing the number of bits required to store each image pixel. In this case, multi-level halftoning could be considered to be a form of image compression.

Gentile et al. describe generalizations of both the conventional error-diffusion and dither techniques for use with multi-level image displays. They report a number of variations for each technique related to the form of the quantizer which is used to map the input color values to the quantized output color values. In particular, they describe two image independent quantizers, a "RGB cubical quantizer" and an "L*u*v* uniform quantizer."

The L*u*v* uniform quantizer is implemented by first transforming the input color value to a uniform color space (such as the well-known and standardized CIE-LUV color space) and performing the quantization in that space. The quantized color values must then be transformed to the output color space. An advantage of this method is that the visibility of the halftone patterns will be more uniform across the color space. The primary drawback is

that the implementation is much more complex than the simple cubical quantizer due to the fact that transformations into and out of the uniform color space must be calculated for each pixel. These transformations involve either a series of mathematical equations or the use of multi-dimensional look-up tables (LUTs).

Consequently, a need exists for a multi-level halftoning method and apparatus for digital images that are simultaneously simple to compute and which produces halftone patterns having reduced noise.

SUMMARY OF THE INVENTION

The need is met according to the present invention by providing a method for multitone processing an N level digital image to produce an M level digital image wherein $M < N$, that includes the steps of: determining M reconstruction levels based on the gray level distribution of the N level image; and applying multilevel dithering to the N level digital image using the M reconstruction levels to produce the M level digital image. In a preferred embodiment of the invention, the M reconstruction levels are selected according to a K-means clustering technique and the multilevel dithering is multilevel error diffusion.

ADVANTAGES

The present invention has the advantage that, instead of conventionally equally spaced reconstruction levels, adaptive reconstruction levels are determined according to the distribution of image pixel values for a given image, resulting in reduced noise in the multilevel dithered output image.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a flow chart describing the processing steps of the present invention;

Fig. 2 is a flow chart describing the K-means clustering technique;

Fig. 3 is a diagram showing a multi-level error diffusion algorithm;

Fig. 4 shows an example set of error weights that can be used for a multi-level error diffusion algorithm;

Fig. 5 is a diagram representing a grayscale histogram partitioned into a number of "cluster" distributions; and

Fig. 6 is a diagram representing a grayscale histogram having a number of "mode" distributions.

DETAILED DESCRIPTION OF THE INVENTION

Referring to Fig. 1, there is shown a block diagram of the present invention for a monochrome input digital image. An N level input digital image is obtained **11** and used to determine a set of M image-dependent, optimal reconstruction levels **12**, where $M < N$, based on the gray level distribution of the N level image. In a preferred embodiment of the present invention, these reconstruction levels are chosen to minimize a mean squared error (MSE) between the N level input digital image and an M level output digital image where each pixel is quantized to the nearest reconstruction level.

A K-means clustering technique is used in the preferred embodiment to partition the values present in the N level input image into K clusters, where K is equal to M, giving rise to M cluster means.

Referring to Fig. 2, there is shown the steps of the K-means clustering technique. First, the number of clusters K is selected to be equal to M **21**. Then initial values for the K cluster centers are chosen **22** either randomly or uniformly spaced in the range of pixel values of the input digital image. Next, each pixel is assigned **23** to the closest cluster center according to the Euclidean distance, which corresponds to minimization of the mean squared error. Cluster centers are then recalculated **24** using all the pixel values assigned to each cluster center. Next, a pre-determined stopping condition is checked **25**. One example of a stopping condition is when the changes in the cluster centers are below a predetermined threshold. If the pre-determined stopping condition is not met,

steps **23** and **24** are repeated. Otherwise, the K-means clustering process is stopped **26**. For more details about the K-means algorithm, see Tou and Gonzalez, Pattern Recognition Principles, Reading MA: Addison-Wesley, 1974. These K cluster means are used as the M optimal reconstruction levels to produce
5 an M level output image. To aid in the clustering process, and to make sure that the dynamic range of the image is optimized, the first and last (highest and lowest) levels of the M levels can be predetermined. For example, the first level can be set to zero, and the last level can be set to the maximum possible level.

Referring to Fig. 5, there is shown a typical histogram of intensity
10 values of an N level input image. Using the K-means algorithm, the histogram is partitioned into M clusters of distribution. The centers of these M clusters (e.g., s1, s2, s3, and s4 as shown in Fig. 5) are selected as the reconstruction levels.

Alternatively, the peaks, also referred to as the “modes”, can be identified, as shown in Fig. 6. The corresponding values of these “modes” (e.g.,
15 t1, t2, t3, and t4 as shown in Fig. 6) can be used as the reconstruction levels.

Referring back to Fig. 1, the M optimal reconstruction levels are then used to apply multi-level dithering **13** to the image to obtain **14** an M level output image. Multi-level dithering can be used to create the appearance of intensity values intermediate to the reconstruction levels by varying the values
20 assigned to the pixels of the output digital image such that the local mean intensity value is preserved. An example of a multi-level halftoning method that could be used would be multi-level error diffusion.

A flow diagram illustrating a typical multi-level error diffusion algorithm is shown in Fig. 3. In this figure, an input pixel value I_{ij} from the i^{th}
25 column and j^{th} row of the input digital color image is processed by assigning **27** a reconstruction level to each image pixel to form a corresponding output pixel value O_{ij} of the output digital image. The assignment of a reconstruction level to each image pixel introduces a quantization error due to the fact that the output pixel value is selected to be one of the reconstruction levels in the determined set
30 reconstruction levels. A difference operation **30** is used to compute an intensity

error E_{ij} representing the difference between the input pixel value I_{ij} and the output pixel value O_{ij} . A errors E_{ij} are weighted by applying 32 a series of error weights W_{ij} to the resulting intensity error E_{ij} . The weighted intensity errors are then added 34 to the nearby input pixels that have yet to be processed.

5 An example set of error weights W_{ij} is shown in Fig. 4. In this example, the intensity error E_{ij} for the current pixel 40 with column and row address (i, j) is weighted by a factor of $1/4$ and distributed to the next pixel to the right 42 in the current row of the image having the column and row address $(i+1, j)$. Likewise the intensity error E_{ij} is also weighted by factors of $1/4$ and
10 distributed to three pixels in the next row of the image 44 having column and row addresses $(i-1, j+1)$, $(i, j+1)$ and $(i+1, j+1)$. In this way, the quantization errors introduced when processing the current pixel 40 are distributed to nearby input pixels that have not yet been processed. The result is that the local mean intensity value is approximately preserved.

15 Conventionally, image-independent, uniformly spaced reconstruction levels are used in a multi-toning process. For example, 0, 85, 170, and 255 are the fixed reconstruction levels if a 4 level dithering is desired for an input image with 256 intensity levels. According to the present invention, image-dependent reconstruction levels are used. By using image-dependent
20 reconstruction levels, there is a high likelihood that the amount of quantization error will be relatively smaller than would otherwise incurs using fixed reconstruction levels at a given pixel. Therefore, there is a lower likelihood for the need to diffuse quantization error to nearby input pixels. The effect of using image-dependent reconstruction levels is less perceived noise in the final multi-
25 level dithered output images.

 Those skilled in the art would recognize that the art taught in the present invention could be extended without departing from the scope of the present teachings. For example, for multi-channel digital images, one straightforward extension is to perform the K-means clustering and multi-level
30 error diffusion on each channel of the multi-channel digital image independently.

Alternatively, the K-means clustering can be performed in the multi-channel space followed by a multi-level dithering such as vector error diffusion. For more details of vector error diffusion, see Gentile, *supra*.

The present invention may be embodied in a computer program
5 product that may include one or more storage media, for example: magnetic
storage media such as magnetic disk (such as a floppy disk) or magnetic tape;
optical storage media such as optical disk, optical tape, or machine readable bar
code; solid-state electronic storage devices such as random access memory
(RAM), or read-only memory (ROM); or any other physical device or media
10 employed to store a computer program having instructions for controlling one or
more computers to practice the method according to the present invention.

The invention has been described in detail with particular reference
to certain preferred embodiments thereof, but it will be understood that variations
and modifications can be effected within the spirit and scope of the invention.

09896798-062901

PARTS LIST

- 11 obtain an input digital image step
- 12 determine reconstruction levels step
- 13 apply multi-level dithering step
- 14 obtain a dithered output image step
- 21 select the number of clusters step
- 22 set initial cluster centers step
- 23 assign pixels step
- 24 recalculate cluster centers step
- 25 stopping condition
- 26 end K-means step
- 27 assign reconstruction level to each image pixel step
- 30 difference operation
- 32 weight errors step
- 34 sum operation
- 40 current pixel
- 42 next pixel to the right
- 44 pixels in next row of image